CLAIMS

That which is claimed is:

1. An organ manipulation apparatus comprising:

a suction member configured to exert sufficient force on an organ to move the organ when the suction member is placed against the organ, a relative negative pressure is established in a space between the suction member and the organ, and the suction member is moved;

a support structure adapted to be substantially rigidly fixed to a relatively immovable object; and

a suspension interconnecting said suction member and said support structure, said suspension allowing at least a limited amount of rotation of said suction member with respect to said support member to accommodate natural movements of the organ.

2. The apparatus of claim 1 wherein said suspension further allows a limited amount of translation of said suction member, along an axis of said suction member, with respect to said support structure.

3. The apparatus of claim 1, wherein said suction member comprises a substantially rigid shaft extending therefrom, and said suspension comprises a roller rotatably mounted in a base member, said roller having an axis of rotation and a bore substantially perpendicular to said axis of rotation, said substantially rigid shaft being mounted in said bore.

4. The apparatus of claim 3, wherein said base member is rotatably mounted to said support structure.

5. The apparatus of claim 4, wherein said base member comprises a biased retention mechanism and said support structure comprises a retention head at an end portion thereof, said retention head adapted to be inserted into said base member to form a snap fit with said retention mechanism.

6. The apparatus of claim 3, wherein said substantially rigid shaft is free to rotate in said bore and is afforded a limited amount of translation with respect to said roller.

7. The apparatus of claim 6, further comprising a biasing member mounted so as to bias said shaft relative to said roller in a direction of said translation.

8. The apparatus of claim 7, wherein said biasing member is a spring coupled between a stop member on said shaft and said roller.

9. The apparatus of claim 3, wherein said substantially rigid shaft is fixed with respect to said roller with respect to translation of said substantially rigid shaft relative to said roller, in a direction along a longitudinal axis of said substantially rigid shaft.

10. The apparatus of claim 9, wherein said base member is flexible, thereby allowing limited amounts of translation of said suction member and said roller with respect to said support structure.

11. The apparatus of claim 10, wherein said base member is sufficiently flexible to allow said limited amounts of translation caused by the beating of a heart when said suction member is attached to the beating heart.

12. The apparatus of claim 10, wherein said base member comprises a clevis, wherein a first end of said roller is inserted in a first arm of said clevis and a second end of said roller is inserted in a second arm of said clevis.

13. The apparatus of claim 10, wherein said base member comprises flexible wires connecting with said roller.

14. The apparatus of claim 13, wherein said base member further comprises a relatively inflexible portion connecting said flexible wires with said support structure.

15. The apparatus of claim 9, wherein said base member is rotatably mounted to said support structure.

16. The apparatus of claim 9, wherein said substantially rigid shaft is rotatably mounted with respect to said roller, said suction member being rotatable relative to said roller.

17. The apparatus of claim 3, further comprising a connector fluidly connected to said substantially rigid shaft and adapted to connect with a source of vacuum, at least a portion of said connector being rotatable with respect to said substantially rigid shaft.

18. The apparatus of claim 1, wherein said suspension comprises an elastomeric tubular member extending from said suction member and adapted to be connected with said support structure.

19. The apparatus of claim 18, wherein said elastomeric tubular member allows a limited amount of translation of said suction member, along an axis of said suction member, with respect to said support structure.

20. The apparatus of claim 18, further comprising first and second stops coaxially mounted with respect to said elastomeric tubular member and defining a mounting section therebetween; and a hook member adapted to snap fit over said mounting section thereby interconnecting said suction member and said support structure, wherein said mounting section is rotatable with respect to said hook member.

21. The apparatus of claim 18, further comprising a connector fluidly connected to said elastomeric tubular member and adapted to connect with a source of vacuum to connect said suction member with the source of vacuum, at least a portion of said connector being rotatable with respect to said elastomeric tubular member, and wherein said elastomeric tubular member is rotatably mounted with respect to said support structure.

22. The apparatus of claim 1, wherein said suspension comprises an elastomeric tubular member interconnecting said suction member and said support structure.

23. The apparatus of claim 22, further comprising a spring positioned within a lumen of said elastomeric tubular member.

24. The apparatus of claim 1, wherein a flexible tubular member extends from said suction member and is adapted to fluidly connect said suction member with a source of

vacuum, said support structure comprising a substantially rigid tubular member, said flexible tubular member passing through said rigid tubular member, and a spring mounted over a portion of said flexible tubular member between said suction member and said substantially rigid tubular member.

25. The apparatus of claim 10, wherein said substantially rigid shaft comprises a substantially rigid tubular member fluidly connected with said suction member, said apparatus further comprising a flexible tubular member extending from said substantially rigid tubular member and adapted to fluidly connect said suction member with a source of vacuum, at least a portion of said support structure comprising a substantially rigid tubular arm, said flexible tubular member passing through said substantially rigid tubular arm.

26. The apparatus of claim 25, wherein at least a portion of said flexible tubular member between said substantially rigid tubular member and said substantially rigid tubular arm is pleated.

27. The apparatus of claim 8, wherein said substantially rigid shaft comprises a substantially rigid tubular member fluidly connected with said suction member, said apparatus further comprising a flexible tubular member extending from said substantially rigid tubular member and adapted to fluidly connect said suction member with a source of vacuum, at least a portion of said support structure comprising a substantially rigid tubular arm, said flexible tubular member passing through said substantially rigid tubular arm.

28. The apparatus of claim 27, wherein at least a portion of said flexible tubular member between said substantially rigid tubular member and said substantially rigid tubular arm is pleated.

29. The apparatus of claim 1, wherein said support structure comprises a substantially rigid tubular arm, said suction member comprises a substantially rigid tubular member extending therefrom, and said suspension comprises a ball having a first passage therethrough and a socket partially constraining said ball but allowing rotation thereof with respect to said socket, said substantially rigid tubular member passing through said first passage, said ball and

socket fluidly connecting said suction member with said substantially rigid arm via an opening in said substantially rigid tubular member.

30. The apparatus of claim 29, wherein said substantially rigid tubular member comprises a closed end forming a stop dimensioned larger than a dimension of said first passage, thereby retaining said substantially rigid tubular member in said first passage.

31. The apparatus of claim 30, further comprising a biasing member mounted between said stop and said ball.

32. The apparatus of claim 29, wherein said socket comprises an annular gap surrounding said ball and fluidly connected to said substantially rigid tubular arm, and wherein said ball comprises a second passage fluidly connecting said first passage with said annular gap.

33. The apparatus of claim 1, wherein the support structure includes an articulating arm have a flexible state and a rigid state, said articulating arm comprising a cable; a plurality of depression disks and balls alternatively threaded over said cable, each of said depression disks having a pair of concave surfaces adapted to engage a pair of said balls; and a tensioning mechanism adapted to apply tension to said cable, wherein said balls and compression disks are compressed against one another upon application of tension to said cable and said articulating arm assumes said rigid state.

34. The apparatus of claim 33, wherein said concave surfaces are harder than said balls.

35. The apparatus of claim 34, wherein said depression disks further comprise recesses in said concave surfaces, wherein, upon said application of tension, said balls contacting said concave surfaces deform and portions thereof at least partially fill said recesses, thereby enhancing rigidity of said rigid state.

36. The apparatus of claim 34, wherein said depression disks further comprise protrusions on said concave surfaces, wherein, upon said application of tension, said

protrusions dig into said balls contacting said concave surfaces, thereby enhancing rigidity of said rigid state.

37. The apparatus of claim 33, wherein said concave surfaces have a central portion formed of a first material that is softer than a second material which forms an outer portion of said concave surfaces, said first material protruding slightly from said second material, and said balls are formed of a material that is harder than said first material, wherein upon said application of tension, said balls contacting said concave surfaces deform said first material, thereby enhancing rigidity of said rigid state.

38. The apparatus of claim 1, wherein said support structure comprises a substantially rigid shaft.

39. The apparatus of claim 1, wherein said support structure comprises a substantially rigid, curved arm.

40. The apparatus of claim 1, wherein said support structure comprises a substantially rigid tubular member.

41. The apparatus of claim 1, wherein said suction member comprises a foam cup, said foam cup having an inside surface and an outside skinned surface, a periphery of said cup being folded over so that the skinned surface is adapted to contact an organ and form a seal therewith.

42. The apparatus of claim 41, further comprising a substantially rigid shaft extending from said outer skinned surface and an opening formed in the skin of said outer skinned surface at a location from which said substantially rigid shaft extends, to fluidly connect said substantially rigid shaft with said inside surface.

43. The apparatus of claim 1, wherein said suction member comprises a silicone cup having an inner lining of open cell foam, wherein said inner lining further comprises a skin at a periphery thereof, said skin adapted to contact an organ and form a seal therewith.

44. The apparatus of claim 1, wherein said suction member comprises a cup having internal grooves adapted to apply negative pressure to a surface of an organ even if the organ is sucked inside said cup to contact an inner surface thereof.

45. The apparatus of claim 1, wherein said suction member comprises a cup having an inner surface and an outer surface, and an organ restraint member adapted to restrain an organ from contacting said inner surface, said organ restraint member and said inner surface defining a vacuum baffle chamber therebetween.

46. The apparatus of claim 45, wherein said organ restraint member comprises webbing.

47. The apparatus of claim 45, wherein said organ restraint member joins said cup to form a highly rounded atraumatic surface adapted to contact an organ.

48. The apparatus of claim 45, wherein said cup comprises silicone.

49. The apparatus of claim 45, wherein said cup is sufficiently rigid to prevent deformation under negative pressures used to grasp a beating heart, said suction member further comprising a foam ring seal adapted to seal said cup with an organ.

50. The apparatus of claim 1, wherein said suction member comprises a first layer made of an air impermeable material and having an inside surface and an outside surface, said first layer having holes therethrough for directing air flow therethrough; a first foam layer adjacent said inside surface; a second foam layer adjacent said outside surface; a tube in fluid connection with said second foam layer; and a second layer made of an impermeable material and sealing said tube and second foam layer with said first layer made of an impermeable material.

51. The apparatus of claim 50, further comprising a thin skirt around a periphery of said suction member, said thin skirt adapted to deform upon contact with an organ to form a seal therewith.

52. The apparatus of claim 1, further comprising a thin skirt around a periphery of said suction member, said thin skirt adapted to deform upon contact with an organ to form a seal therewith.

53. The apparatus of claim 1, wherein said suction member comprises a foam inner layer and an air impermeable outer layer, said air impermeable outer layer having at least one opening therethrough fluidly connecting a vacuum tube to said foam inner layer.

54. The apparatus of claim 53, further comprising a flexible, air impermeable skirt surrounding a periphery of said suction member and adapted to deform upon contact with an organ to form a seal therewith.

55. The apparatus of claim 53, wherein said air impermeable outer layer has a plurality of openings therethrough connecting a plurality of vacuum tubes to said foam inner layer.

56. The apparatus of claim 1, wherein said suction member comprises an air impermeable layer having an inner surface and an outer surface, said air impermeable layer having at least one opening therethrough fluidly connecting a vacuum tube to said inner surface, and a foam donut adjacent said inner surface and surrounding each said vacuum tube.

57. The apparatus of claim 1, wherein said suction member comprises an air impermeable cup and a telescoping soft sleeve having a retracted position and an extended position, wherein said telescoping soft sleeve is biased toward said extended position.

58. The apparatus of claim 57, further comprising a vacuum tube passing through said cup and fluidly connecting with an interior of said cup; and open-celled foam adjacent said vacuum tube and filling at least a portion of said interior, said open-celled foam adapted to diffuse air flow.

59. The apparatus of claim 1, wherein said suction member comprises a pleated cup.

60. The apparatus of claim 1, wherein said suction member comprises a compliant seal around a perimeter thereof, said compliant seal being substantially C-shaped in cross section and deformable to conform to the shape of a surface of an organ upon contact therewith.

61. The apparatus of claim 1, wherein said suction member comprises a compliant seal within a perimeter thereof, said compliant seal being a substantially flat flange and deformable to conform to the shape of a surface of an organ upon contact therewith.

62. The apparatus of claim 61, further comprising a foam seal member mounted to said flange.

63. The apparatus of claim 62, wherein said flange has a variable radius.

64. The apparatus of claim 1, wherein said suction member comprises a saddle-shaped tissue contact surface.

65. The apparatus of claim 1, wherein said suction member is elliptically shaped.

66. The apparatus of claim 1, wherein said suction member is oval-shaped.

67. The apparatus of claim 1, wherein said suction member comprises a tissue contact surface, and at least a portion of said tissue contact surface is curved or non-planar.

67. An organ manipulation apparatus comprising:

a suction member configured to exert sufficient force on an organ to move the organ when the suction member is placed against the organ, a relative negative pressure is established in a space between the suction member and the organ, and the suction member is moved;

a support structure adapted to be inserted through a small opening in a body of a patient;

a coupling member into which said support structure is fitted after insertion of said support structure through the small opening; and

a flexible suspension interconnecting said suction member and said coupling member.

68. The apparatus of claim 67, wherein said coupling member is rotatable with respect to said support structure after coupling said support structure and said coupling member.

69. The apparatus of claim 67, wherein said flexible suspension comprises a flexible tubular member that allows a limited amount of translation of said suction member along an axis of said suction member, with respect to said support structure.

70. The apparatus of claim 67, wherein said flexible suspension comprises an elastomeric tubular member that allows a limited amount of translation of said suction member along an axis of said suction member, with respect to said support structure.

71. The apparatus of claim 67, wherein said flexible suspension comprises a flexible tubular member that allows a limited amount of torsion of said suction member along an axis of said suction member, with respect to said support structure.

72. The apparatus of claim 67, wherein said flexible suspension comprises an elastomeric tubular member that allows a limited amount of torsion of said suction member along an axis of said suction member, with respect to said support structure.

73. The apparatus of claim 67, wherein said coupling member is a quick-release coupling.

74. The apparatus of claim 67, further comprising a binding member adapted to prevent advancement of said support structure further into the body once the support structure has been positioned as desired.

75. The apparatus of claim 74, further comprising a vacuum tube extending from said support structure and adapted to fluidly connect said support structure and suction member with a source of vacuum, wherein said binding member comprises a binding ring adapted to bind on said vacuum tube.

76. The apparatus of claim 75, wherein said binding ring comprises a contact surface having a periphery larger than a periphery of the small opening, and a drag member having a

first position that allows said binding ring to slide freely over the vacuum tube, and a second position, that binds said drag member against said vacuum tube.

77. A surgical method performed on a beating heart comprising the steps of:

applying a suction member of a manipulation device to a surface of the heart;

creating suction between the suction member and surface of the heart;

moving the suction member to retract the heart into a position that provides access to a surgical site that would be difficult or impossible to access without retraction;

connecting the suction member with a compliance mechanism attached to a support arm; and

fixing the support arm with respect to a stationary object, wherein the compliance mechanism permits at least limited translation of the heart and suction member with respect to the support arm.

78. The method of claim 77, wherein the suction member and heart are rotatable with respect to the support arm.

79. The method of claim 77, further comprising the steps of:

contacting a surgical target area on the heart with a stabilizer in the vicinity of the surgical target to stabilize the surgical target; and

performing a surgical procedure on the surgical target.

80. The method of claim 79, further comprising fixing the stabilizer to a stationary object prior to said performing a surgical procedure.

81. The method of claim 79, wherein said contacting with a stabilizer comprises contacting with a suction stabilizer and applying suction to grasp tissue in the vicinity of the surgical target.

82. The method of claim 79, wherein said contacting with a stabilizer comprises applying mechanical pressure to tissue in the vicinity of the surgical target.

83. A surgical method performed on a beating heart comprising the steps of:

providing a manipulation device having a suction member, a support arm, and a compliance mechanism interconnecting the suction member and support arm and permitting at least limited translation and rotation of the suction member with respect to the support arm;

applying the suction member of the manipulation device to a surface of the heart;

creating suction between the suction member and surface of the heart;

moving the suction member to retract the heart into a position that provides access to a surgical site that would be difficult or impossible to access without retraction; and

fixing the support arm with respect to a stationary object, wherein the compliance mechanism permits at least limited translation and rotation of the heart and suction member with respect to the support arm.

84. The method of claim 83, further comprising the steps of:

contacting a surgical target area on the heart with a stabilizer in the vicinity of the surgical target to stabilize the surgical target; and

performing a surgical procedure on the surgical target.

85. The method of claim 84, further comprising fixing the stabilizer to a stationary object prior to said performing a surgical procedure.

86. The method of claim 84, wherein said contacting with a stabilizer comprises contacting with a suction stabilizer and applying suction to grasp tissue in the vicinity of the surgical target.

87. The method of claim 84, wherein said contacting with a stabilizer comprises applying mechanical pressure to tissue in the vicinity of the surgical target.

88. A surgical method performed on a beating heart comprising the steps of:

providing a manipulation device having a suction member, a support arm, and a suspension interconnecting the suction member and support arm and permitting at least limited movement of the suction member with respect to the support arm;

accessing the beating heart of a patient;

contacting the suction member of the manipulation device to a surface of the heart;

creating suction between the suction member and surface of the heart so that the suction member grasps the surface of the heart;

moving the suction member to retract the heart into a position that provides access to a surgical site that would be difficult or impossible to access without retraction;

contacting tissue of the heart at or near the surgical site with a stabilizer and stabilizing the surgical site; and

performing a surgical procedure at the surgical site.

89. The method of claim 88, further comprising the step of fixing the support arm with respect to a stationary object after the step of moving the suction member to retract the heart.

90. The method of claim 88, wherein the suspension permits at least limited translation and rotation of the heart and suction member with respect to the support arm.

91. The method of claim 88,further comprising applying suction through a contact member of the stabilizer contacting the heart tissue to perform the stabilization of the surgical site.

92. The method of claim 91, further comprising fixing the stabilizer to a stationary object.

93. The method of claim 88,further comprising applying mechanical force through a contact member of the stabilizer contacting the heart tissue to perform the stabilization of the surgical site.

94. The method of claim 93, further comprising fixing the stabilizer to a stationary object.

95. A surgical method performed on a beating heart comprising the steps of:

accessing the beating heart of a patient;

contacting a suction member of an organ manipulation device to a surface of the heart;

creating suction between the suction member and surface of the heart so that the suction member grasps the surface of the heart;

moving the suction member to retract the heart into a position that provides access to a surgical site that would be difficult or impossible to access without retraction;

contacting tissue of the heart at or near the surgical site with a stabilizer and stabilizing the surgical site; and

performing a surgical procedure at the surgical site.

96. The method of claim 95, further comprising the step of connecting a support arm to the suction member and fixing the support arm with respect to a stationary object after the step of moving the suction member to retract the heart.

97. The method of claim 96, wherein the suspension permits at least limited translation and rotation of the heart and suction member with respect to the support arm.

98. A system for performing beating heart coronary artery bypass grafting, said system comprising:

an organ manipulation device having a suction member configured to exert sufficient force on the beating heart to move the beating heart when the suction member is placed against a surface of the heart, a relative negative pressure is established in a space between the suction member and the heart, and the suction member is moved; a support structure adapted to be substantially rigidly fixed to a relatively immovable object; and a suspension interconnecting said suction member and said support structure, said suspension allowing at least a limited amount of rotation of said suction member with respect to said support member to accommodate natural movements of the beating heart;

a stabilizer device having at least one contact member adapted to contact the surface of the beating heart at or adjacent a location where an anastomosis is to be performed; and

a sternal retractor, wherein said support arm and said stabilizer are adapted to be fixed to said sternal retractor.

99. The system of claim 98, wherein said suspension further allows a limited amount of translation of said suction member, along an axis of said suction member, with respect to said support structure.

100. A system for performing beating heart coronary artery bypass grafting, said system comprising:

an organ manipulation device having a suction member configured to exert sufficient force on the beating heart to move the beating heart when the suction member is placed against a surface of the heart, a relative negative pressure is established in a space between the suction member and the heart, and the suction member is moved; a support structure adapted to be substantially rigidly fixed to a relatively immovable object; and a suspension interconnecting said suction member and said support structure, said suspension allowing at least a limited amount of rotation of said suction member with respect to said support member to accommodate natural movements of the beating heart; and

a stabilizer device having at least one contact member adapted to contact the surface of the beating heart at or adjacent a location where an anastomosis is to be performed.

101. The system of claim 100, wherein said suspension further allows a limited amount of translation of said suction member, along an axis of said suction member, with respect to said support structure.